

By R. S. Montgomery and A. E. Strong

Coral Bleaching Threatens Ocean, Life

People around the world depend on the resources provided by the ocean to support life. But global-scale damage to the coral reefs, a large and integral part of the ocean environment that supports a variety of sea life, is a frightening scenario that may unfold in the coming years.

Recently, a phenomenon called coral bleaching has raised concerns about the deteriorating conditions in the world's oceans and the implications for life on our planet. Coral bleaching occurs as coral tissue expels zooxanthellae, a symbiotic alga that resides in the structure of the coral and is essential to its survival. The widespread nature of the bleaching threatens the state of the environment.

The zooxanthellae, besides giving color to the otherwise white coral skeleton, produce carbon compounds that nourish the coral. In return, the coral provides the algae with a home inside its skeletal structure and nitrogen and phosphorous, which are essential for its survival [Brown and Ogden, 1993].

This delicate symbiosis can be disrupted by several factors, and this causes the coral to expel the algae. Disturbances such as extremes of temperature, hypersalinity, pollutants in the water, or changes in radiation flux cause coral bleaching. The correlation between high water temperatures and coral bleaching is of acute concern.

In the 1980s, many reefs including those near Easter Island, the Great Barrier Reef, and the coasts of Central America showed signs of bleaching.

More noticeable events occurred in 1983 near Panama and in 1987-1988 in the Caribbean [Ghiold, 1990]. The Panama event is connected with the 1982-1983 El Niño, which raised water temperatures in the area to above 29°C.

The Caribbean event, which lasted for 9 months, was associated with widespread bleaching in the reefs off Jamaica. Water temperatures in the area were above 30°C at the peak of the bleaching. This event in particular raised concerns about a possible link between coral bleaching, rising water temperatures, and global warming [Goreau et al., 1993].

The possibility that a recent warming trend in the world's oceans is responsible for the recent bleaching events merits further inquiry. Evidence favoring this hypothesis exists in oceanic and atmospheric physical data, but until such evidence is examined with known bleaching events, conclusions cannot be made.

Cases of Elevated Water Temperature and Coral Bleaching

During 1982 and 1983, an extremely strong El Niño/Southern Oscillation (ENSO) event coincided with widespread, permanent coral bleaching across the equatorial eastern Pacific [Glynn, 1991]. This ENSO event marked the strongest warming of the equatorial Pacific this century, and it affected coral reefs from Panama to Japan [Brown and Suharsono, 1990]. The waters of the eastern Pacific warmed 3-4°C over the seasonal average.

Glynn [1991] tracked the event and concluded that the elevated temperatures resulted in massive bleaching of coral along the coast of Central America and beyond. Ultimately, reefs off the coasts of Costa Rica, Ecuador, Panama, Colombia, and the Galapagos Islands were affected [Roberts, 1987].

Recent studies by Brown and Ogden [1993] have confirmed the suspicion that elevated water temperatures caused the bleaching event. The widespread nature of this event was illustrated by the bleaching that occurred in 1983 on the other side of the Pacific.

At Pari Island in the Thousand Island chain of Indonesia, Brown and Suharsono [1990] found that water temperatures 2-3°C higher than normal contributed to coral mortality.

The evidence for the 1987 Caribbean event is not as clear as the 1983 ENSO episode. It reached its peak in December 1987 and was complete by March 1988 [Roberts, 1987]. An extended period of elevated temperature is most likely responsible for the bleaching in the area. Corals normally thrive between 25 and 29°C. This narrow range of temperatures is also very close to the upper tolerance for a coral. An increase of one or two degrees above the usual maximum temperature can be deadly [Brown and

Ogden, 1993].

Procedure

The first coral bleaching event in Bermuda was recorded in the summer of 1988 (Figure 1). This event coincided with the highest water temperatures ever recorded in the 38 years that records have been kept at the Bermuda Biological Station for Research (BBS).

The temperature was registered at Hydrostation S, which is located at 32°10'N/64°30'W (Figure 2). To study this event and determine a temperature index at which bleaching will occur, a 1982–1991 record of Multi-Channel Sea Surface Temperatures (MCSST) from NOAA's Advanced Very High Resolution Radiometer was examined and validated using coincident in-situ SST readings at Hydrostation S.

Initially both daytime and nighttime MCSST data were examined using composite weekly averages at 18-km resolution. A grid-point time-series was generated from the MCSST temperatures at 31°50'N/64°10'W, the location of the Bermuda Atlantic Time-Series Study (BATS) station.

This location, to the southeast of both Bermuda and Hydrostation S, was selected to ensure minimal influence from higher radiation off the land surface.

Since the extracted MCSST temperature represented a weekly composite value, each was assigned a date in the middle of the week from which the image was derived. The MCSST temperature could then be matched most closely with daily in-situ temperature values obtained from shipboard measurements at 1-m depth.

Preliminary analysis of daytime and nighttime MCSST revealed a consistently higher "offset" – MCSST minus in-situ SST – in the daytime dataset of nearly +0.10°C. Much of this offset can be attributed to heating of the surface waters during the day.

The bias for nighttime MCSST values is –0.04°C, significantly MCSST fares better in these comparisons with in-situ SST, the remainder of this study considers only nighttime MCSST. The MCSST series plotted against the in-situ SST series reveals a remarkably close correlation (see Figure 3).

Results

Although the MCSST and the in-situ temperature series show a close correlation, there are a few intervals when offsets are significant.

Examining the time-series for 1982 and 1983 (Figure 3), the in-situ temperatures are visibly higher than MCSST during certain times of the year. In April 1982, the El Chichón volcano erupted in Mexico, throwing a large cloud of dust and gas into the atmosphere. Biases for 1982 and 1983 were –0.83°C and –0.43°C, respectively.

These large negative offsets were due to absorption of solar radiation by sulfuric acid particles formed from gases in the volcanic cloud. A similar phenomenon occurred in June 1991 when Mount Pinatubo erupted in the Philippines [Strong and Stowe, 1993]. For several months, the aerosols associated with that eruption also caused the MCSST values to be significantly lower than in-situ temperatures for several months at may tropical locations, including Bermuda.

Because aberrations in the accuracy of MCSSTs caused by volcanic eruptions were absent from 1984 to 1990, this period was optimal for validation of the nighttime MCSST data and assessment of its use as a potential coral reef bleaching indicator. For this period, the overall offset was virtually zero, –0.03°C, the standard error was 0.54°C, and the variance was 0.97.

In Bermuda, the most prominent, documented case of coral bleaching occurred in 1988 when ocean temperatures reached their highest levels in 38 years. During a 6-week period from August 6 to September 17, the average MCSST temperature was 28.1°C. This corresponds to the period of most extensive bleaching [Cook et al., 1990].

MCSST data shows surface temperatures were sustained at 28.3°C for a 2-week period from August 2 to 16. On August 15, BBS measured SST at 29.1°C; from September 7 to 13, MCSST attained the highest weekly level for the 1980s–28.5°C (see Figure 1).

After the first bleaching event, two more events occurred, both of lesser magnitude than the first. In 1990, from August 26 to September 10, the average temperature again reached 28.1°C. This coincided with a "moderate" bleaching event off Bermuda. Again in 1991, from August 3 to September 14, the average temperature climbed to 28.3°C. During August 3_9 and August 17_23, MCSST again reached 28.5°C. This higher-than-normal temperature was accompanied by a strong bleaching event.

Based on the three periods of recorded bleaching and their associated temperatures, 28°C is a good index for gauging bleaching events in the Bermuda region. Each time the temperature crosses the 28°C threshold, a bleaching event occurred. It is likely that in the future, similar temperature extremes will cause some bleaching on the Bermuda coral reefs. Note that this index is unique to the Bermuda area and based on SST at BBS's Station-S. Where tropical corals have adapted to warmer waters, we would expect their threshold for bleaching would be higher.

Although coral bleaching is a problem throughout the world, the limited scope of the studies done thus far have not exposed any significant trend implying a steady regional or global-scale warming of the oceans.

To spot significant trends, the scope of investigation must be widened to examination of long-term time-series on a worldwide scale. Comparing a well-distributed series of these time-series with air-sea coupled numerical models could prove instrumental for identifying site-specific global warming signals useful for the verification of global climate scenarios. This will require continued and expanded study and data collection of temperatures, including their correlation to coral bleaching.

We thank the folks at RSMAS for their assistance during the data processing: Sue Walsh, Jim Brown, and Robert Evans. E. P. McClain provided valuable insights during proofing the manuscript. We are also indebted to the cosigners of the Memorandum of Understanding between NOAA/NESDIS and the Navy's U.S. Naval Academy, who actively support the Cooperative Project in Oceanic Remote Sensing.

- R. S. Montgomery, U.S. Naval Academy, Annapolis, Md.;
- A. E. Strong, Cooperative Project in Oceanic Remote Sensing, NOAA/NESDIS and USNA, Annapolis, Md.

References

- Brown, B. E., and J. C. Ogden, Coral Bleaching, *Sci. Am.*, 268, 64, 1993.
- Brown, B. E., and Suharsono, Damage and recovery of coral reefs affected by El Niño related seawater warming in the Thousand Islands, Indonesia, *Coral Reefs*, 8, 153, 1990.
- Cook, C. B., A. Logan, J. Ward, B. Luckhurst, and C. J. Berg, Elevated temperatures and bleaching on a high latitude coral reef: The 1988 Bermuda event, *Coral Reefs*, 9, 45, 1990.
- Ghiold, J., White death – The fate of a deserted coral, *New Scientist*, 238, 46, 1990.
- Goreau, T. J., R. L. Hayes, J. W. Clark, D. J. Basta, and C. N. Robertson, Elevated satellite sea surface temperatures correlate with Caribbean coral reef bleaching, in *A Global Warming Forum: Scientific, Economic, and Legal Overview*, pp. 226_255, edited by R. A. Geyer, CRC Press, Boca Raton, Fla., 1993.
- Glynn, P. W., Coral reef bleaching in the 1980s and possible connections with global warming, *Trends Ecol. Evol.*, 6, 175, 1991.
- Roberts, L., Coral bleaching threatens Atlantic reefs, *Science*, 238, 1228, 1987.
- Strong, A. E., and L. L. Stowe, Comparing stratospheric aerosols from El Chichón and Mount Pinatubo using AVHRR data, *Geophys. Res. Lett.*, 20, 1183, 1993.
- Fig. 1. MCSST (deg C) composite image for September 7-13, 1988, when significant bleaching occurred. Bermuda is the black dot under the "m" in Bermuda.
- Fig. 2. Map of Bermuda showing the location of Hydrostation S (in-situ SSTs) and BATS station (MCSST). (Courtesy of BBS -- revised)
- Fig. 3. MCSST versus in-situ SST at Bermuda Biological Station – "S."